

## UvA-DARE (Digital Academic Repository)

### Anisotropic Variation of $T_c$ and $T_n$ in $URu_2Si_2$ by Uniaxial Pressure

Bakker, K.; Devisser, A.; Menovsky, A.A.; Franse, J.J.M.; Bruck, E.H.

DOI

[10.1016/0304-8853\(92\)91349-X](https://doi.org/10.1016/0304-8853(92)91349-X)

Publication date

1992

Published in

Journal of Magnetism and Magnetic Materials

[Link to publication](#)

#### Citation for published version (APA):

Bakker, K., Devisser, A., Menovsky, A. A., Franse, J. J. M., & Bruck, E. H. (1992). Anisotropic Variation of  $T_c$  and  $T_n$  in  $URu_2Si_2$  by Uniaxial Pressure. *Journal of Magnetism and Magnetic Materials*, 108, 63-64. [https://doi.org/10.1016/0304-8853\(92\)91349-X](https://doi.org/10.1016/0304-8853(92)91349-X)

#### General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

#### Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

# Anisotropic variation of $T_c$ and $T_N$ in $\text{URu}_2\text{Si}_2$ by uniaxial pressure

K. Bakker, A. de Visser, E. Brück, A.A. Menovsky and J.J.M. Franse

*Van der Waals–Zeeman Laboratorium, Universiteit van Amsterdam, Valckenierstraat 65, 1018 XE Amsterdam, Netherlands*

The effect of uniaxial stress on the superconducting and magnetic transition temperature in the heavy-fermion system  $\text{URu}_2\text{Si}_2$  has been investigated by means of resistivity measurements. The uniaxial pressure effects on  $T_c$  and  $T_N$  are inversely connected:  $T_c$  increases and  $T_N$  decreases for a stress along the tetragonal axis, while a stress in the plane results in the opposite effect.

The unusual coexistence of superconductivity ( $T_c \approx 1$  K) and antiferromagnetic order ( $T_N = 17.4$  K) [1] in the tetragonal heavy-fermion compound  $\text{URu}_2\text{Si}_2$  has given rise to speculations about an unconventional pairing mechanism in the superconducting state, i.e. Cooper pairing mediated by antiferromagnetic interactions instead of by the usual electron-phonon interaction. Evidence for the coexistence of magnetism and superconductivity comes mainly from neutron-scattering experiments [2]. The ordered moment in  $\text{URu}_2\text{Si}_2$  is extremely small ( $|\mu| = (0.03 \pm 0.01)\mu_B/\text{f-atom}$ ) [2]. The question arises whether this small ordered moment can give rise to two superconducting transitions as recently reported for the small-moment superconductor  $\text{UPt}_3$  [3]. The double superconducting transition in  $\text{UPt}_3$  is possibly explained by a lifting of the order parameter by a symmetry-breaking field (the small ordered moment) [4]. However, as the moment in  $\text{URu}_2\text{Si}_2$  is oriented along the tetragonal ( $c$ ) axis, the crystal symmetry is not broken. A possible other way to induce several superconducting phases in a superconductor with non-trivial pairing, is by a lattice distortion brought about by uniaxial stress [5]. In this paper we report on the first investigations of the effect of a uniaxial stress ( $P_i \leq 2$  kbar) on  $T_c$  and  $T_N$  of  $\text{URu}_2\text{Si}_2$  by means of resistivity measurements.

As we were afraid to damage the single-crystalline sample by pressurizing, we used a specimen with moderate superconducting properties. The crystal was grown by a modified tri-arc Czochralski method using a very high pulling rate (100 mm/h). No additional annealing was applied. The crystal was shaped into a rectangular bar (dimension  $0.76$  ( $c$ -axis)  $\times$   $0.80$  ( $a$ -axis)  $\times$   $2.62$  ( $a$ -axis)  $\text{mm}^3$ ) by means of sparc erosion. The residual resistance ratio,  $\rho(300 \text{ K})/\rho(1.5 \text{ K})$ , amounts to 18. The crystal was mounted in a uniaxial pressure cell made of a beryllium-copper alloy [6]. The pressure was applied either along the  $c$ -axis or along the (short)  $a$ -axis. Pressure was monitored by strain gauges that measure the calibrated deformation of the cell. The absolute uncertainty in the pressure determination amounts to 10%, while the relative accuracy amounts to 0.02 kbar. After each run, the cell and sample were warmed up to room temperature in order to change the pressure. The resistivity was measured with a stan-

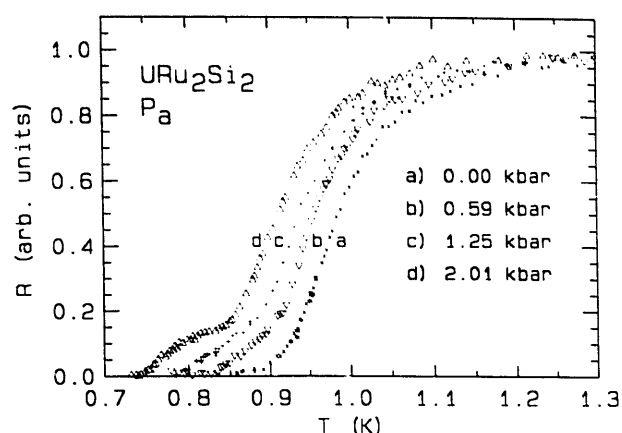


Fig. 1. Superconducting transition of single-crystalline  $\text{URu}_2\text{Si}_2$  for uniaxial pressure (as indicated) along the  $a$ -axis.

dard ac-technique (with the current along the long  $a$ -axis).

The superconducting and antiferromagnetic transitions measured resistively, for a pressure along the  $a$ -axis ( $P_a$ ), are shown in figs. 1 and 2, respectively. The data are normalized to 1 (at 1.5 K in fig. 1 and at  $T_N$  in fig. 2), because of small irreproducibilities in the absolute value of the resistivity. These irreproducibilities (5% of the absolute resistivity value) are caused by

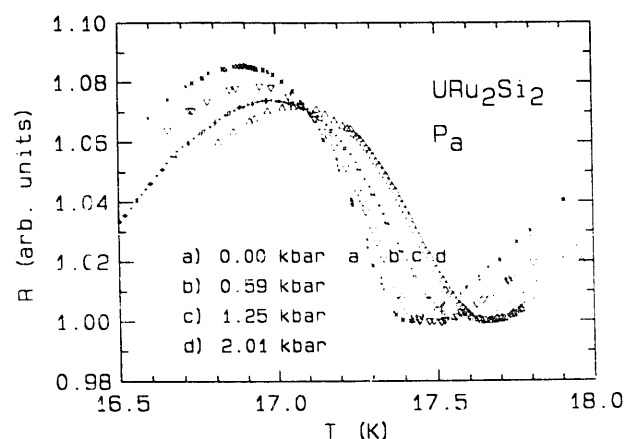


Fig. 2. Antiferromagnetic transition of single-crystalline  $\text{URu}_2\text{Si}_2$  for uniaxial pressure (as indicated) along the  $a$ -axis.

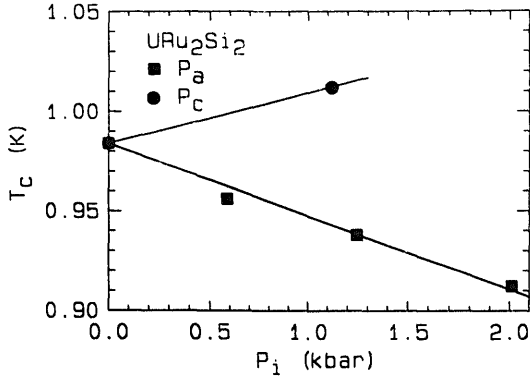


Fig. 3.  $T_c$  of single-crystalline  $URu_2Si_2$  as function of uniaxial pressure along the  $a$ - (■) and  $c$ -axis (●).

small changes of the voltage contacts at thermal cycling and by cracks at applying pressure. A stress of 2 kbar along the  $a$ -axis left the sample intact. The crystal appeared to be much weaker for a stress along the  $c$ -axis: for  $P_c$  larger than  $\sim 1$  kbar it broke (also a second crystal broke at about the same pressure). A shoulder appeared at the low-temperature side of the superconducting transition with increasing pressure along the  $a$ -axis. After releasing the pressure, the value of  $T_c$ , as obtained before pressurizing, reproduced, but a trace of the shoulder remained. The appearance of a second transition (indicated by the shoulder) is likely connected to a sample inhomogeneity [7], and not to the appearance of a second superconducting phase. The transitions do not broaden noticeably under pressure, indicating a rather homogeneous pressure.

The variations of  $T_c$  and  $T_N$  with  $P_a$  and  $P_c$  are shown in figs. 3 and 4.  $T_c$  has been determined by the midpoint of the transition, while  $T_N$  has been determined by the local minimum in  $R(T)$ . Note that  $T_c$  increases and  $T_N$  decreases for  $P_c$ , while for  $P_a$  the opposite effects is observed. In a first approximation the pressure variation is taken as linear:  $dT_c/dP_a = -35$  mK/kbar,  $dT_c/dP_c = 25$  mK/kbar,  $dT_N/dP_a = 126$  mK/kbar and  $dT_N/dP_c = -41$  mK/kbar. The present data can be compared with the hydrostatic

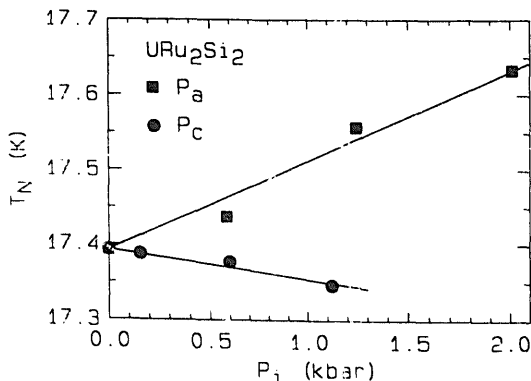


Fig. 4.  $T_N$  of single-crystalline  $URu_2Si_2$  as function of uniaxial pressure along the  $a$ - (■) and  $c$ -axis (●).

pressure dependence of  $T_c$  and  $T_N$  by taking  $dT_{c,N}/dP = dT_{c,N}/dP_c + 2dT_{c,N}/dP_a$ , yielding  $dT_c/dP = -45$  mK/kbar and  $dT_N/dP = 211$  mK/kbar. Specific-heat measurements under hydrostatic pressure yield  $dT_c/dP = -56$  mK/kbar and  $dT_N/dP = 127$  mK/kbar [8], whereas resistivity measurements under hydrostatic pressure yield  $dT_c/dP = -95$  mK/kbar [9] and  $dT_N/dP = 130$  mK/kbar [9,10]. Similar values have been deduced from the discontinuities in the thermal expansion and the specific heat at  $T_c$  and  $T_N$  using the Ehrenfest relation [6,11,12]. The reported values for  $dT_c/dP$  and  $dT_N/dP$  are somewhat at variance with each other, which is probably related with the reported sample inhomogeneity [7]. It has been suggested that the inverse correlation of  $T_c$  and  $T_N$ , as follows from the hydrostatic pressure experiments, is consistent with superconductivity and antiferromagnetism (of the spin-density wave type) competing for parts of the Fermi surface [9]. As the inverse correlation of  $T_c$  and  $T_N$  also holds for uniaxial pressure, further support for this idea is provided.

The work of one of us (AdV) was made possible by a fellowship of the Royal Netherlands Academy of Arts and Sciences. This work is partially supported by a NEDO grant (Japanese New Energy and Industrial Technology Organization).

## References

- [1] T.T.M. Palstra et al., Phys. Rev. Lett. 55 (1985) 2727; W. Schlabit, Z. Phys. B 62 (1986) 171; M.B. Maple et al., Phys. Rev. Lett. 56 (1986) 185.
- [2] C. Broholm, J.K. Kjems, W.L.J. Buyers, P. Matthews, T.T.M. Palstra, A.A. Menovsky and J.A. Mydosh, Phys. Rev. Lett. 58 (1987) 1467.
- [3] R.A. Fisher, S. Kim, B.F. Woodfield, N.E. Phillips, L. Taillefer, K. Hasselbach, J. Flouquet, A.L. Giorgi and J.L. Smith, Phys. Rev. Lett. 62 (1989) 1411.
- [4] R. Joynt, Superc. Sci. Technol. 1 (1988) 210.
- [5] M. Sigrist, R. Joynt and T.M. Rice, Phys. Rev. B 36 (1987) 5186.
- [6] K. Bakker et al., to be published.
- [7] A. Ramirez, T. Siegrist, T.T.M. Palstra, J.D. Garrett, E. Brück, A.A. Menovsky and J.A. Mydosh, Phys. Rev. B 44 (1991) 5392.
- [8] R.A. Fisher, S. Kim, Y. Wu, N.E. Phillips, M.W. McElfresh, M.S. Torikachvili and M.B. Maple, Physica B 163 (1990) 419.
- [9] M.W. McElfresh, J.D. Thompson, J.O. Willis, M.B. Maple, T. Kohara and M.S. Torikachvili, Phys. Rev. B 35 (1987) 43.
- [10] F.R. de Boer, J.J.M. Franse, E. Louis, A.A. Menovsky, J.A. Mydosh, T.T.M. Palstra, U. Rauchschwalbe, W. Schlabit, F. Steglich and A. de Visser, Physica B 138 (1986) 1.
- [11] A. de Visser, F.E. Kayzel, A.A. Menovsky, J.J.M. Franse, K. Hasselbach, A. Lacerda, L. Taillefer, J. Flouquet and J.L. Smith, Physica B 165 & 166 (1990) 375.
- [12] A. de Visser, F.E. Kayzel, A.A. Menovsky, J.J.M. Franse, J. van den Berg and G.J. Nieuwenhuys, Phys. Rev. B 34 (1986) 8168.